Impact of Air-Sea Interaction Research on Larger-Scale Geophysical Flows

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LONG-TERM GOALS

My long-term goals are to contribute improvements to our current physical understanding and modeling skills for interfacial processes fundamental to air-sea interaction fluxes, particularly those involving wave breaking. Closely allied is the complementary goal of utilizing these advances to improve the reliability of operational sea state and ocean weather forecasting models.

OBJECTIVES

I am seeking to better identify and understand the perceived needs of the larger-scale modeling community in terms of fundamental sensitivities and knowledge gaps in parameterizing air-sea interfacial processes and the associated boundary conditions. I am especially interested in investigating the role of wave breaking in this context, with the aim of improving fundamental understanding and developing more realistic parameterizations for breaking occurrence and strength.

APPROACH

I am undertaking a two-year study involving technical discussions with researchers at key international air-sea interaction and larger-scale oceanographic/meteorological research centers. A significant aspect of this project is to identify and explore knowledge gaps and establish collaborative research on related key air-sea interaction problems that impact on these gaps. Having identified wave breaking as one such area, I have initiated further analyses of existing unique datasets based on recent advances in our understanding of wave breaking. In FY00, this has involved a significant collaboration with David Farmer (IOS, Canada) and his co-workers. One project aims to determine wave breaking probability in the open ocean in frequency bands above the wind sea spectral peak. A second study involves an extended analysis of a dataset comprising breaking noise and velocities of individual breaking waves [Ding and Farmer (1994a,b)] to obtain new insight on the spectral 'strength' of breaking events.

WORK COMPLETED

During FY00, I had targeted discussions with a number of colleagues whose research interests depend strongly on parameterizations of air-sea interaction processes. These include D. Halpern (JPL, Pasadena, A. Moore (U. Colorado, Boulder), J. McWilliams (UCLA), W.K Melville (SIO, La Jolla), S. Godfrey (CSIRO, Hobart), L. Leslie (UNSW, Sydney) and F. Bradley (CSIRO, Canberra). In FY00, I also visited the Jet Propulsion Laboratory, Scripps Institute of Oceanography, University of Miami, Johns Hopkins University, Princeton University, Johns Hopkins University, UCLA and ONR headquarters. In addition to the targeted research discussions, during my travel I presented research seminars on recent developments in understanding wave breaking in terms of nonlinear wave group dynamics. I also had extensive strategic research discussions with a number of potential High Wind CBLAST DRI collaborators during the planning letter development stage.

I had intensive scientific meetings with David Farmer (at Scripps and in Miami) related to the quantification of wave breaking probability and strength in the physical and spectral domains. We reviewed in detail the results of our further analyses of his existing datasets and discussed outcomes and refinements.

I attended the GasTransfer Symposium 2000 in Miami where I presented a paper on the surface kinematics of microscale breaking waves and their potentially central role in an extended surface renewal model for air-sea gas transfer rates.

RESULTS

(1) Large-Scale Impact of Small-Scale Processes

There is an active research focus on *coupled* atmosphere-ocean models on a range of space and time scales, from synoptic weather systems and meso-scale ocean eddies, to ocean basin scales. Typically, the idealized ‘research’ models being used to validate and/or explain basic mechanisms are computationally very expensive to run at high resolution and investigators seek to minimize the amount of detailed testing on sensitivity to sea surface boundary conditions. Hence there is a strong demand for optimal surface flux parameterizations, including variability, for the available model spatial resolution. This need is also very strongly reflected within the operational modeling community.

While not abundant, cases of convincing evidence exist for significant forecast sensitivity to sea surface boundary conditions for both atmospheric and sea state variables, particularly in synoptic severe marine weather predictions. Examples are highlighted in the recent work of Janssen (2000) and Buckley and Leslie (2000), amongst others.

Further evidence of the potential global impact of small-scale air-sea interaction (ASI) processes is contained in the recent insightful essay by McWilliams and Sullivan (2000), who evaluate the importance of incorporating fundamental small-scale ASI processes such as wind waves into planetary scale ocean circulation. While wind waves were found not to modify Ekman pumping and interior geostrophic flow, wave transport can have a marked effect on the general upper ocean circulation (McWilliams and Restrepo, 1999). They identified other wave-related issues of potential impact on large-scale flows: Langmuir circulations, misaligned wind and wave fields, departures from Monin-Obhukov similarity structure, near-surface flow separation (especially over breaking waves), contributions to air-sea fluxes from wave-correlated winds and currents including the effects of wave breaking on near-surface flow structures and fluxes, and mesoscale inhomogeneity and non-stationarity. They signal a research focus on the strength and distribution of breaking events as fundamental to an improved understanding of ASI dynamics and energetics.

(2) Small-Scale Air-Sea Interaction Processes

Sea state dependence of air-sea fluxes has been a strong focus of recent air-sea interaction research. Within this, the role of wave breaking on various scales has been receiving increasing attention, yet even basic issues such as the occurrence statistics (probability) of wave breaking and the optimal environmental controlling variables is poorly understood.

My collaboration with David Farmer (IOS) and Johannes Gemmrich (IOS) involved further analysis of their open ocean dataset (FG99) on breaking waves, described in Gemmrich and Farmer (1999). This dataset uniquely reports the detection of open ocean wave breaking events for wind wave frequencies both at and above the spectral peak frequency. Whitecaps were detected by an air void fraction sensor mounted on a floating sub-surface raft, which also carried a device to detect the wave elevation or acceleration. The data was collected for a wide range of sea state conditions.

Following the promising results for parameterizing the breaking probability of the dominant wind sea waves, as reported in Banner, Babanin and Young (2000), the FG99 dataset was re-analyzed using a measure of mean steepness of the wave field as the primary correlation variable rather than the traditional wind forcing strength. To avoid the issue of choice of bandwidth in estimating the mean wave steepness, we explored the use of the spectral saturation as an appropriate local wave steepness spectral parameter. Also, in our analysis we were careful to exclude background swells.

When correlated in terms of the significant wave steepness, the FG99 breaking probabilities conformed closely to the Banner, Babanin and Young (2000) results around the wind sea spectral peak region. In addition to the close agreement between datasets, this correlation is characterized by negligible breaking below a threshold mean steepness, but a rapid increase of breaking probability above that threshold.

The FG99 dataset allowed us to investigate for the first time the possible existence of similar threshold behavior in spectral bands above the spectral wave peak region. Figure 1 below shows our results for three values of f/f_{peak}, spanning the spectral region out to twice the peak frequency (f_{peak}). As mentioned above, we used the smoothed azimuthally-integrated spectral saturation σ_f (= $k^4 F(\omega)$) as a measure of spectral steepness that is not sensitive to the choice of spectral bandwidth.

This correlation of the data establishes for the first time that the shorter wave components above the spectral peak have a qualitatively similar threshold behavior to that found at the spectral peak by Banner, Babanin and Young (2000). While certain features of these observations need to be further investigated, this result provides new observational support for relating breaking wave properties to nonlinear modulating wave train behavior and for the local spectral wave steepness as the primary controlling variable for parameterizing breaking onset for waves shorter than the dominant wind sea. When formulated within the framework of the wave spectrum, we believe that this will lead to significant improvements in the dissipation source function in operational wind wave modeling and forecasting.

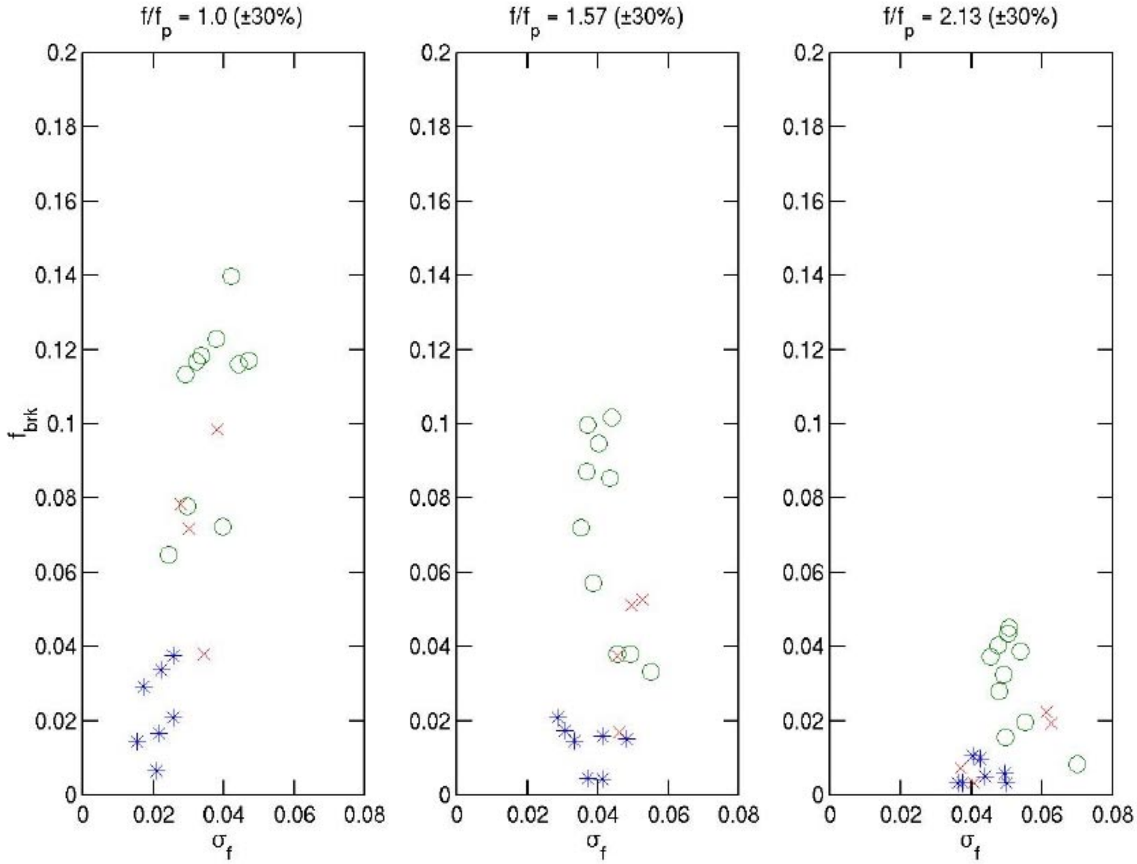

Figure 1. Breaking probability as a function of spectral saturation for three frequency bands relative to the spectral peak f/f_p=1, f/f_p=1.57 and f/f_p=2.13. Each frequency band spans ±30% of the center frequency. Each panel shows the data from three NE Pacific deployments: (*) expt III (U_{10}~11-16 ms^{-1}, SWH~4-4.8 m); (o) expt IV (U_{10}~12-20 ms^{-1}, SWH~4-6.6 m) and (x) expt V (U_{10}~10-14 ms^{-1}, SWH~3-3.8 m)

IMPACT/APPLICATIONS

An improved scientific understanding of small-scale processes, particularly wave breaking, will provide more reliable parameterizations of these processes and of a number of basic air-sea fluxes. These improved parameterizations will lead to significant improvements in the reliability of sea state and marine meteorological forecasts, especially during severe marine wind conditions. These improved parameterizations should also enhance system performance in larger-scale modeling applications, as recently published model sensitivity studies indicate that traditional 'small-scale' phenomena (e.g. wind waves, Langmuir cells, atmospheric roll cells) can impact significantly the modeling of larger-scale ocean and atmospheric circulation.

TRANSITIONS

The results of this project have not progressed sufficiently to be utilized by others.

RELATED PROJECTS

The ONR project *Source Term Balance for Finite Depth Wind Waves* (Young, Banner and Donelan) includes a strong focus on observations of wave breaking in a constant depth shallow water environment. The results of the present study for deep water conditions motivate a similar analysis for the recently-gathered Lake George shallow water dataset. This will be pursued in FY01.

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